The Surface Energy Balance in the Indian Monsoon

Summary

This project will focus on the interaction between atmospheric circulations, rainfall, and land surface processes in the Indian monsoon. The student will analyse high quality in situ data covering several years from three locations in India. From this the student will develop an understanding of the surface energy balance for the Indian monsoon season, the effect of rainfall on the land surface, and how land surface processes feed back on the atmospheric circulation and rainfall. This can be used to improve the next generation of weather and climate models, improving prediction of monsoon rainfall.

Project Description

The Indian summer monsoon is a dramatic seasonal change in atmospheric circulation and precipitation, bringing the majority of the year's rainfall to the subcontinent between June and September. This rainfall is not distributed uniformly in space or time. For example, the Western Ghats mountains on India's west coast – the site of devastating floods in July and August 2018 – receive up to three times the average rainfall for India as a whole. Meanwhile, rainfall in central and northwestern India is more intermittent. The monsoon is also characterised by active (rainy) and break (dry) spells that typically last a few weeks; the timing of these spells has a huge impact on agriculture.

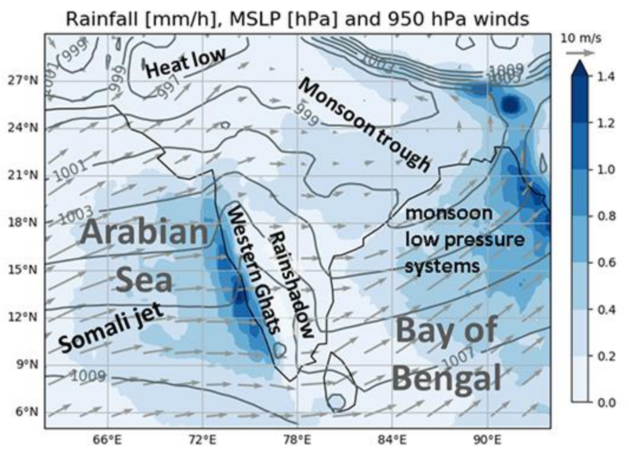
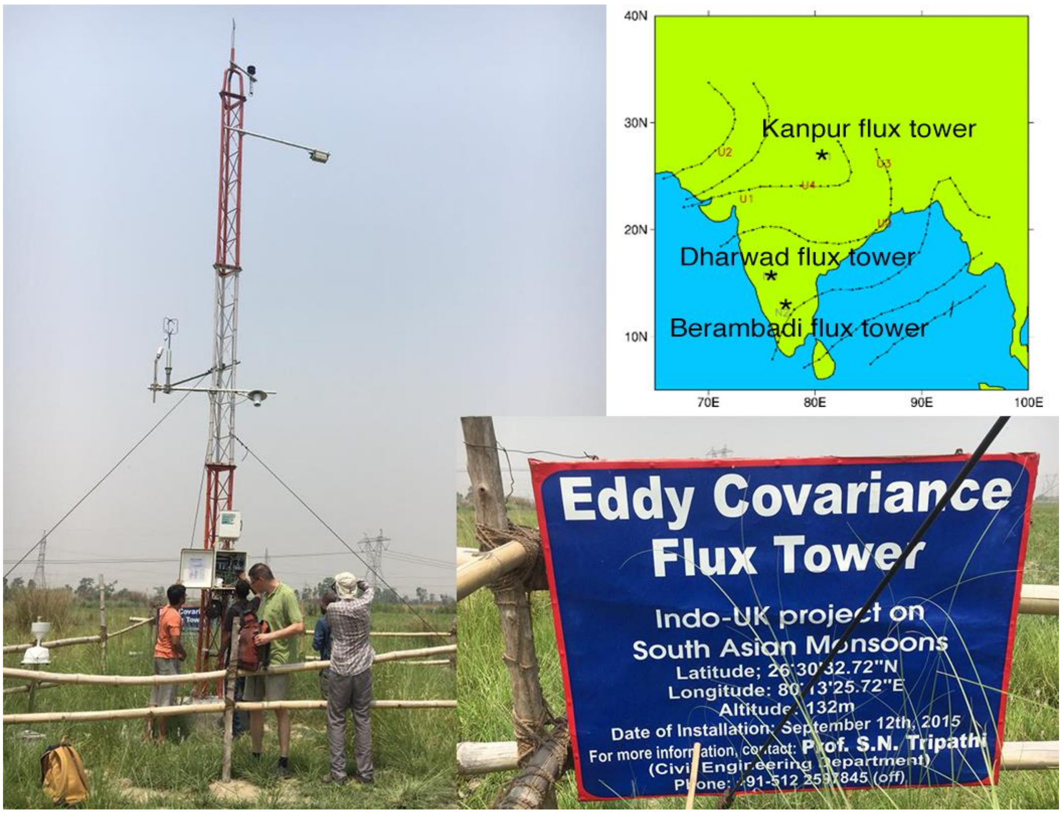


Figure 1: Left: a waterfall in the Western Ghats mountains during the monsoon (photo: Jennifer Fletcher). Right: the main features of the Indian monsoon.

The monsoon presents a challenge for both conceptual understanding and prediction. Processes affecting the monsoon range in scale from individual cloud elements to continental scale circulations. Unsurprisingly, this range of scales makes the Indian monsoon difficult to predict, with many climate models, including the Met Office Unified Model, having a severe and persistent dry bias in the region (Sperber et al, 2013). One of the problems in understanding and predicting the monsoon is moisture sources: e.g., what is the relative importance of remote transport of water vapour into the region by the continental-scale monsoon circulation compared to the recycling of water from the land surface as the monsoon progresses? Relatedly, what role do pre-monsoon showers, which moisten the dry land surface, play in the progression of the monsoon into northwestern India in June and July (Parker et al, 2016)?

Because of these gaps in understanding and predicting the Indian monsoon, a joint Indian-UK programme called INCOMPASS has brought about new state of the art observations of atmospheric and land processes in the monsoon. These include the installation of permanent flux towers: ground-based measurement sites which measure the transfer of heat, moisture, and radiation between the land surface and the atmosphere, in addition to standard meteorological measurements and precipitation. The flux towers were installed in early 2016 at three sites capturing a range of rainfall regimes within the monsoon: two in the rainy Western Ghats mountains and one in Kanpur in northern India. Preliminary analysis (Bhat and Morrison et al, 2019) has already shown that the seasonal evolution of surface fluxes – the transfer of heat and moisture between the land surface and atmosphere – is quite different between the sites as a result of their different surface types. Other results (Fletcher et al, 2018) have suggested that early in the monsoon season the surface energy balance is very sensitive to precipitation, with rainfall leading to a substantial increase in evaporation and hence recycling of water vapour back into the atmosphere. This recycling is likely important for the development of the monsoon early in the season, but weather and climate models struggle to capture this



process.

Figure 2: Left and lower right: the INCOMPASS flux tower in Kanpur, Northern India. Upper right: flux tower locations. (Photos: Jennifer Fletcher)

We now have three full monsoon seasons’ worth of data from INCOMPASS flux towers and the successful student will be well-positioned to interrogate that data more fully. This includes examining the land surface response to rainfall on a range of time scales, from sub-daily to seasonal. This will improve understanding of key processes in the initiation of convection and in the seasonal evolution of the monsoon over both southern and northern India. The improved understanding of how the surface responds to convection can be tested in stand-alone versions of the Unified Model’s land surface scheme, JULES. This will be an opportunity to contribute to improvements in the Unified Model in one of the regions it most struggles to simulate.

Key questions for PhD project

- After rainfall events, how long does it take soil moisture to dry down and surface evaporation to reduce back to what it was before the rain? How does that change between locations, over the course of the season, and according to the nature of the rainfall event?
- How does the diurnal cycle of rainfall and surface fluxes change over the course of the season at the three sites? Does the diurnal amplitude go down as the monsoon progresses? How does the diurnal cycle respond to active and break phases of the monsoon?
- Preliminary results from the INCOMPASS intensive field campaign in 2016 suggest that rainfall on the lee of the Western Ghats is preceded by flow up from the valleys in the rainshadow, flow which is itself likely a response to surface heating. Is this observed in the multi-season dataset? Does it change over the course of the monsoon?
- What key processes are land surface models missing in order to accurately represent the response of the land surface to convection in the Indian monsoon?

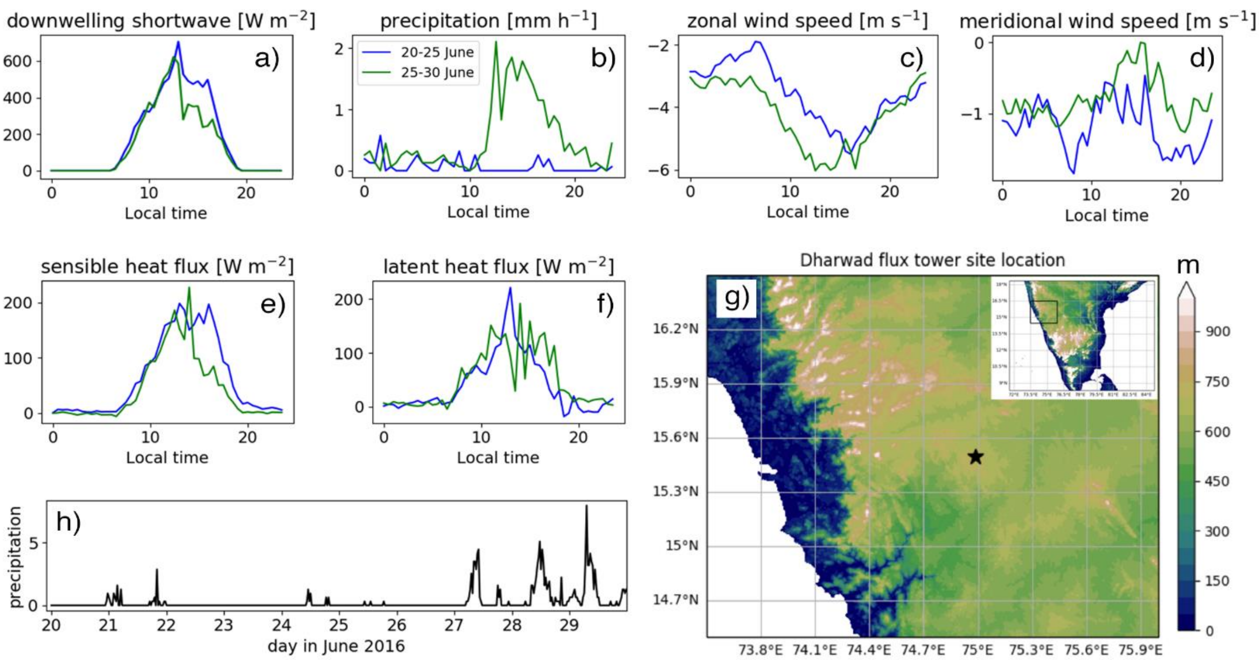


Figure 3: Preliminary results from a flux tower in the Western Ghats mountains, showing the strong drop in sensible heat fluxes after rainfall.

What the student will do

- Analyse several years of surface energy balance data from a new climate station network in India
- Refine and develop theoretical models for the moisture and energy balances over India
- Link the new understanding to weather and climate models
- Perform model simulations implementing the new understanding
- Publish high impact papers on the surface energy balance over India

Impact

Through this project, the student will develop an understanding of the response of the land surface to convection on a range of time scales and over a variety of environments in the Indian monsoon. This understanding can be compared to experiments with stand-alone versions of the JULES land surface model, and processes that JULES is failing to represent can be identified, with an opportunity to suggest model changes. The Met Office Partnership will give the student a direct route to influence model development.

Furthermore, the Indian dry bias is not unique to the Unified Model; it has remained one of the most prominent and persistent biases in climate models (Sperber et al, 2013). The results from this work therefore have the potential to be implemented in many climate models in addition to the UM.

Training

The Student will work with Professor Douglas Parker and Dr Jennifer Fletcher, both in the Dynamics and Clouds research group in ICAS. Dr Fletcher is additionally a member of the National Centre for Atmospheric Science. In this project the student will receive high level training in the following: 1) analysis and interpretation of in situ and remote sensing observations; 2) numerical modelling and scientific computing. The successful student will also gain deep expertise on tropical atmospheric dynamics and their interaction with the land surface. Co-supervision will involve regular meetings with Dr Christopher Taylor, an expert in tropical atmospheric dynamics and land surface processes, either at Leeds or the Centre for Ecololgy and Hydrology in Wallingford where Dr Taylor is based. The student will have access to many training workshops on a range of topics.

Student profile

The successful student should have a strong background in a quantitative science (meteorology, maths, physics, engineering, environmental sciences) and an interest in the dynamics of the atmosphere. A willingness to travel to India would be ideal, though it is not required.

References

- Sperber, K.R., Annamalai, H., Kang, I.S., Kitoh, A., Moise, A., Turner, A., Wang, B. and Zhou, T., 2013. The Asian summer monsoon: an intercomparison of CMIP5 vs. CMIP3 simulations of the late 20th century. *Climate Dyn.*, *41*(9-10), 2711-2744.

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